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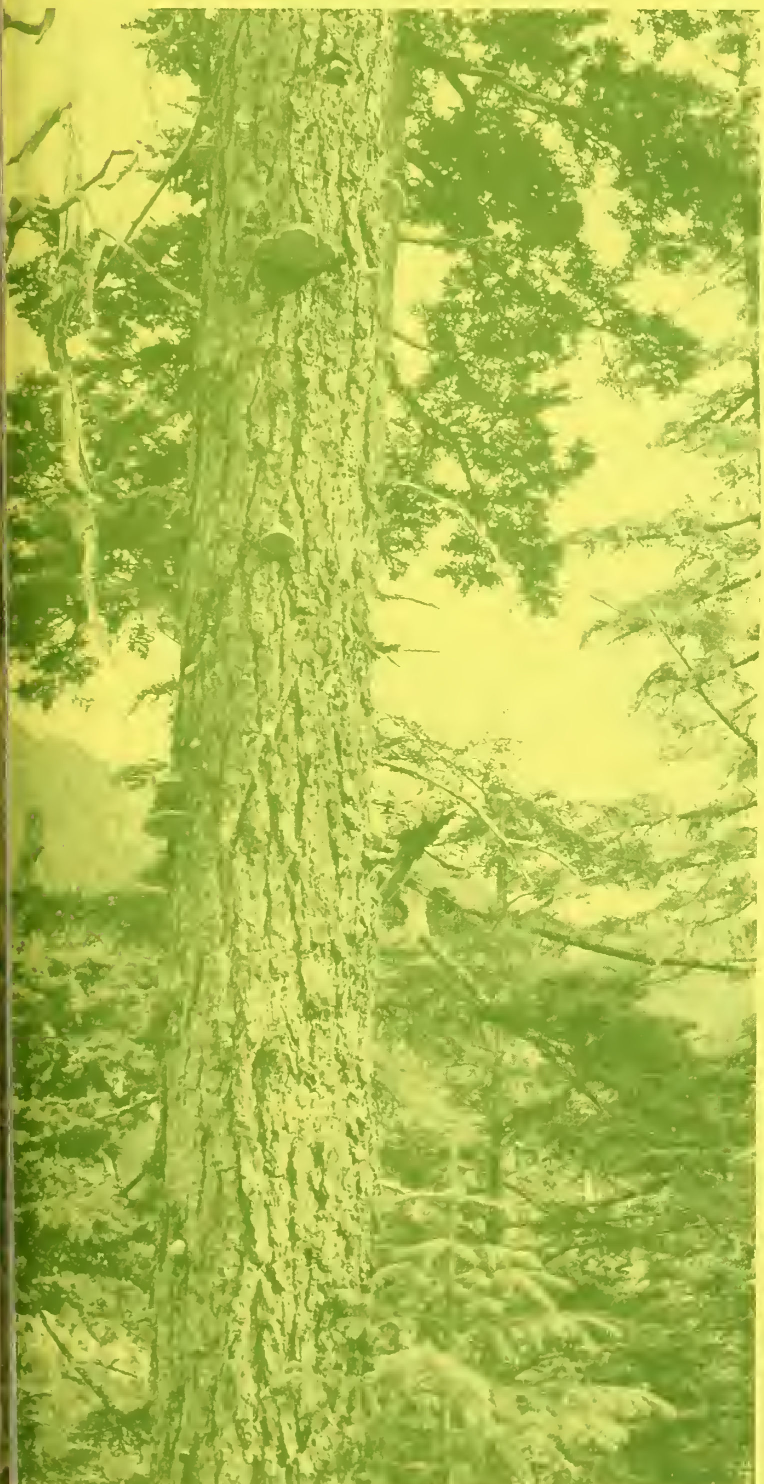
Estimation of Decay in Old-growth Western Hemlock and Sitka Spruce in Southeast Alaska



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Cover: *Fomes pinicola*, shown here on western hemlock, is responsible for about 22 percent of the internal decay in western hemlock and 73 percent of the decay in Sitka spruce (Kimmey 1956).

Contents

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ESTIMATION OF DECAY IN OLD-GROWTH WESTERN HEMLOCK AND SITKA SPRUCE IN SOUTHEAST ALASKA

Reference Abstract

Farr, Wilbur A., Vernon J. LaBau, and Thomas H. Laurent
1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-204, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees on sixty seven 1/5th-acre plots were dissected so that a method could be developed for making unbiased estimates of decay in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on commercial forest land in southeast Alaska. Decay in both species was related to many variables, but relationships were weak. For hemlock, decay was best related to position of external indicators and to geographic location; decay in hemlock increased to the north. For spruce, the most useful predictor of decay was position of external indicators. These derived decay factors are useful for large-scale inventories; their reliability cannot be guaranteed on local timber sales.

KEYWORDS: Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, decay (-log quality.

RESEARCH SUMMARY

Research Paper PNW-204

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The forests of southeast Alaska consist mostly of defective stands of old-growth western hemlock and Sitka spruce. On the average, total defect accounts for about 31 percent of the gross board-foot volume.

For the past 20 years, timber cruisers in the region have estimated wood loss in standing trees from tables of decay factors based on the location of external indicators of decay and tree diameter (Kimmey 1956). In some instances this has worked satisfactorily, but net scaled volume removed from sale areas often differs considerably from cruised net volume. Many factors contribute to these differences, but foresters in the region have for many years suspected that type and amount of decay is so variable from area to area that the decay factor tables themselves may be a significant source of error. So, a study of tree decay was begun on commercial forest land to see if an improved method for estimating decay in standing trees could be developed. Trees on sixty seven 1/5th-acre plots were felled and dissected.

External indicators such as basal and trunk scars, frost cracks, broken tops in the merchantable stem, conks, swollen knots caused by *Fomes pini*, rotten stubs, and rotten burls were found to be significantly related to internal decay in hemlock and spruce. Certain injuries and imperfections, like dead and broken tops above the merchantable stem, large dead branches or sucker-type limbs, forked tops, dead sides, sound burls, sound mistletoe cankers, and conks more than a foot from the stem on branches, were not consistent indicators of decay. Most external indicators of decay were located on the lower stem; and when indicators were found on the upper stem, the tree usually had an indicator on the lower stem as well. Decay percentages in hemlock and spruce were significantly related to position of external indicators, tree age, and tree diameter, although the relationships were weak. Decay percentages in hemlock were also related to latitude.

Development of equations to predict decay was difficult, as coefficients of variation often exceeded 200 percent. Decay was highly variable and use of various tree characteristics in regression accounted for little of the total variation. Decay percentages in hemlock also generally increased from south to north, indicating that geographic location was an important variable. In the final analysis, the prediction equation for hemlock included just two variables--position of external indicator and geographic location (table 1). Constant or flat decay factors based solely on position of external indicators were developed for spruce (table 2).

The new decay factors are easier to apply than those used previously, since tree diameter need not be known. Rather, there is a table of constant or flat factors for each species. Development of a more complicated estimation procedure could not be justified.

Prospective users of these decay factors are cautioned that they were developed from data collected throughout southeast Alaska. Therefore, their reliability cannot be guaranteed if they are applied to local timber sales. They should only be used for large cruises and extensive inventories.

We believe there is no reliable way to obtain estimates of decay in standing hemlock and spruce trees on a sale basis in southeast Alaska unless sample trees are felled and sectioned.

Table 1--*Decay in percent of gross cubic- and board-foot volume in western hemlock in southeast Alaska by position of external indicator and geographic area*

Position of external indicator	Geographic area			
	Ketchikan	Petersburg	Sitka	Juneau
	- - - - - - - - *Percentage* - - - - - - - -			
Cubic-foot decay[1/]				
0 None	0	2.0	6.7	10.2
1 Above the first 32-foot log	8.4	10.4	15.2	18.7
2 On the first 32-foot log	12.4	14.4	19.2	22.7
3 Both on and above the first 32-foot log	29.1	31.1	35.8	39.4
Board-foot decay[2/]				
0 None	.9	6.3	13.7	22.4
1 Above the first 32-foot log	19.7	25.1	32.4	42.2
2 On the first 32-foot log	27.3	32.7	39.9	49.8
3 Both on and above the first 32-foot log	54.7	60.1	67.4	77.2

[1/] Based on the regression $Y = 8.44x_1 + 12.45x_2 + 29.13x_3 + 1.95x_4 + 6.71x_5 + 10.24x_6$, where $x_1 = 1$ for indicators above the first 32-foot log; $x_2 = 1$ for indicators on the first 32-foot log; $x_3 = 1$ for indicators both on and above the first 32-foot log; $x_4 = 1$ for trees in the Petersburg area; $x_5 = 1$ for trees in the Sitka area; $x_6 = 1$ for trees in the Juneau area; all are 0 otherwise. Standard error of estimate = 13.61 or 134.5 percent of the mean. $R^2 = 0.35$.

[2/] Scribner rule. Based on the equation $Y = 0.91 + 18.79x_1 + 26.37x_2 + 53.78x_3 + 5.41x_4 + 12.66x_5 + 22.47x_6$. Standard error of estimate = 26.67 or 119.4 percent of the mean. $R^2 = 0.35$.

Table 2--*Means and standard errors of decay percentages for Sitka spruce in southeast Alaska by position of external indicator*[1/]

Position of external indicator	Sample size	Cubic-foot decay		Board-foot decay (Scribner rule)	
		Mean decay percentage	Standard error of the mean	Mean decay percentage	Standard error of the mean
0 None	194	0.4	0.12	1.3	0.37
1 Above the first 32-foot log	9	7.8	4.70	15.6	8.39
2 On the first 32-foot log or, both on and above the first 32-foot log	42	16.0	2.73	33.9	4.75

[1/] Separation of the data into classes by position of external indicator accounted for 37 percent of the variation in cubic-foot decay percentages and 43 percent of the variation in board-foot decay percentages.

Introduction

Southeast Alaska consists of the Alexander Archipelago and a narrow mainland strip along the Pacific Ocean between 55^{o} and 60^{o} north latitude (fig. 1). Because of its rugged relief and proximity to the ocean, the area has a moist maritime climate with abundant rainfall throughout the year and infrequent periods of hot, dry summer weather.

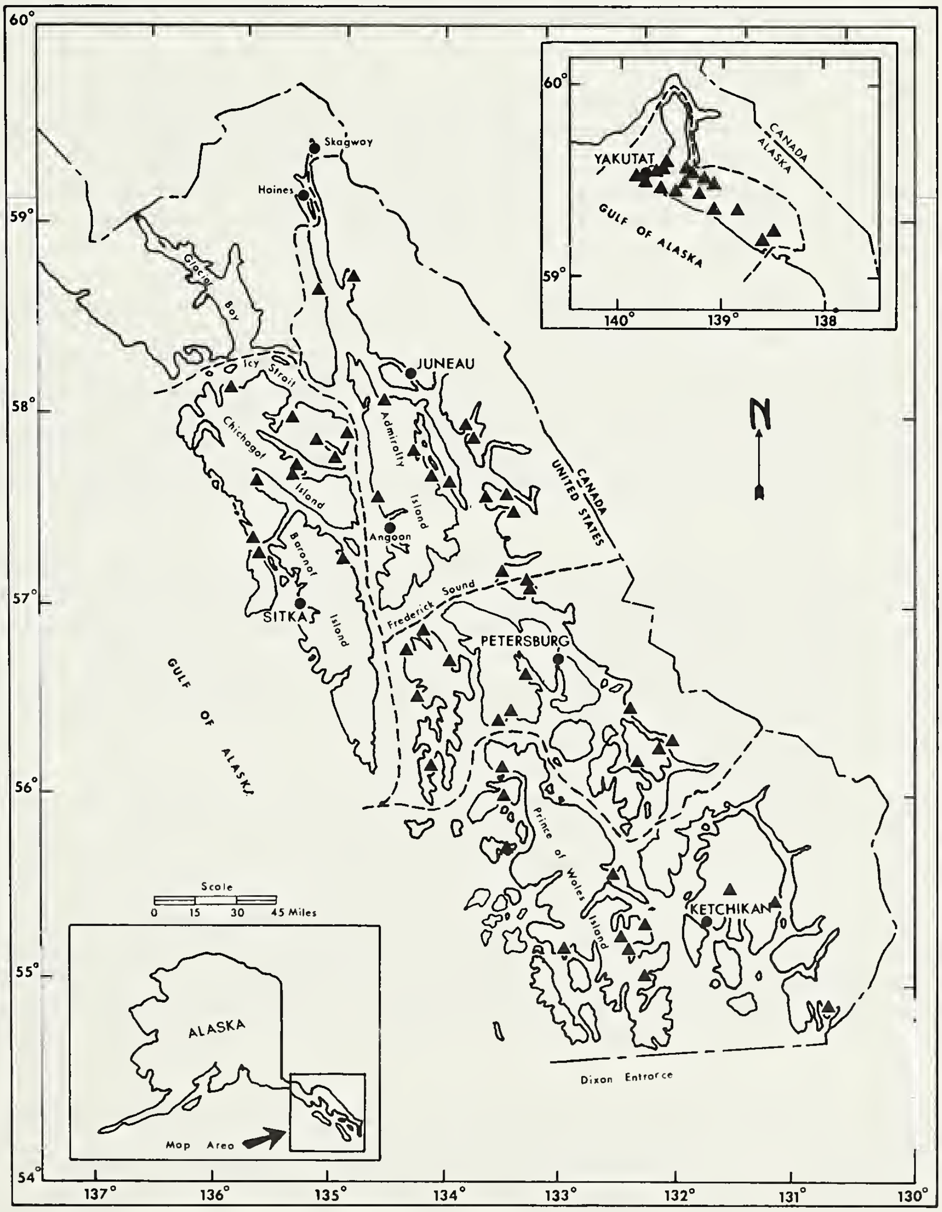

Figure 1.--Location of 67 cull study plots in southeast Alaska.

About 89 percent of the forest area of the region is in mixed stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) with the two species making up 64 and 28 percent, respectively, of the cubic-foot growing stock volume (Hutchison 1967). Appearance and condition of these stands vary considerably, but most are defective, with total defect accounting for about 31 percent of the gross board-foot volume.[1/] Because of the large amount of defect and great variation in decay, it is difficult for cruisers to estimate net volumes of standing trees. In years past when timber values were relatively low, it was sufficient for sales purposes to have approximate estimates of net volume; but now it is becoming increasingly important that more precise estimates be obtained.

Timber cruisers in southeast Alaska generally use tables to estimate decay in standing trees, based on the location of external indicators and tree diameter (Kimmey 1956). Kimmey's tables, however, seem best suited to large-scale surveys where decay percentages tend to average out. Because of large standard errors associated with these tables, biased estimates often result when they are applied to small sales.

In 1961, Bones[2/] tested Kimmey's tables on 21 active logging shows. He found that scaled net volume on a sale basis ranged from 30 to 143 percent of cruised net volume, but that total cruised net volume for all sales combined was only 2.1 percent higher than total scaled net volume, indicating that the decay factors provided a useful measure of total decay when applied over a large area. However, the factors tended to overestimate decay in western hemlock and underestimate decay in Sitka spruce. Decay in western redcedar (*Thuja plicata* Donn) was greatly overestimated.

The study reported here was started in the late 1960's to develop a method for making unbiased estimates of decay for hemlock, spruce, and cedar on commercial forest land[3/] in southeast Alaska. However, only the hemlock and spruce data were analyzed, as there were too few cedars sampled. Data collected by Kimmey in the 1950's were also reanalyzed, but the two sets of data were not pooled, as merchantability standards and sampling methods were different for each study.

Preliminary results of the study were reported by LaBau and Laurent (1974). Included here are new decay factors for hemlock and spruce, along with measures of their precision. The new factors are easier to apply than those used previously since tree diameter need not be known. This study shows that decay in western hemlock and Sitka spruce in southeast Alaska is highly variable and not easily estimated. External indicators of decay and various tree characteristics are significantly but weakly correlated with percentage of interior decay. Use of broad constant or flat factors to estimate decay are as useful as more complicated functions.

1/ Forest survey statistics on file at the Forestry Sciences Laboratory, Juneau, Alaska.

2/ Bones, J. T. 1964. Estimating cull in southeast Alaska tree species. Unpublished report. For. Sci. Lab., Juneau, Alaska.

3/ Commercial forest land is defined as land available for timber production and capable of growing stands containing 8,000 board feet (International 1/4-inch rule) of timber per acre (Hutchison 1967).

Past Investigations

A general lack of knowledge concerning the biology of forest fungi in hemlock and spruce and amounts of associated decay has led to many disease studies in British Columbia and the Pacific Northwest. Few detailed studies of tree diseases have been conducted in southeast Alaska. Only the most important literature will be reviewed here, as a detailed summary was recently published (Laurent 1974).

Relative importance of rot fungi attacking hemlock and spruce changes with latitude and elevation (Buckland 1946, Englerth 1942, Foster et al. 1958, Kimmey 1956, 1964, 1965). *Echinodontium tinctorium* (Ellis and Everh.), the Indian paint fungus, for example, causes severe damage to western hemlock in northern Idaho and upper Columbia region of British Columbia (Foster et al. 1954, Weir and Hubert 1918), little damage in Oregon and Washington (Englerth 1942), and none in southeast Alaska. The species, however, has been reported in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) in Prince William Sound (Ellis 1895). *Fomes pinicola* (Swartz ex Fr.) Cke., a major cause of decay in southeast Alaska (Kimmey 1956), is a scavenger fungus in the Pacific Northwest States and not a major cause of decay in living trees (Englerth 1942).

Fomes pini (Thore ex Fr.) Karst is also of lesser importance in southeast Alaska than in the contiguous Pacific Northwest States and British Columbia. Decay resulting from this fungus lessens northward and westward and switches to mountain hemlock, suggesting that the importance of this fungus changes with latitude and altitude.

Decay organisms responsible for rot in the coastal forests are mostly heart- and root-rotting fungi which cause large losses of wood plus increased logging and milling costs. Although many species are present, they can be grouped into two broad classes, the white rots and the brown rots. This classification is a bit loose, but generally the white rots are caused by fungi that decompose all components of the wood and the brown rots, by fungi that attack the cellulose, leaving the lignin more or less unaffected. Wood attacked by the white rot fungi is sometimes usable for pulp in the early stages of decay, but wood attacked by brown rot fungi is useless for pulp or construction. Kimmey (1956) estimated 22 percent of the western hemlock and 4 percent of the Sitka spruce cubic-foot decay to be incipient white rot.

Roots, wounds, and branch stubs serve as the main infection courts for decay fungi attacking western hemlock and Sitka spruce. When conks of these decay fungi are found, the organism can be readily identified. Unfortunately, relatively few conks are produced on living trees in the Queen Charlotte Islands (Bier et al. 1946, Foster and Foster 1952) or in coastal Alaska.

Studies of forest diseases in Alaska began in the 1930's when the late Dow Baxter, then professor of Forest Pathology at the University of Michigan, began making periodic survey and collecting trips to both interior and coastal Alaska. Little use was being made of the timber at the time, and the forest disease information was mainly of academic interest. Demand however, changed in the early 1940's as high-quality

Sitka spruce was then sought for aircraft construction (American Forests 1942, Johnson 1943). The need for high-quality saw logs generated interest in Sitka spruce diseases, as experience showed that certain defects and poor handling resulted in a great waste of effort and material. A high percentage of the timber was found unsuitable for aircract construction. Information obtained by Baxter on several trips to southeast Alaska (Baxter 1947) and laboratory tests of relative rates of growth of various fungi provided the basis for recommendations on how to select and transport high-quality spruce logs (Baxter and Varner 1942).

Englerth (1947) also contributed to our knowledge of Sitka spruce decays during this period. In response to a request from the Alaska Spruce Log Program, Englerth spent part of 1942 and 1943 in southeast Alaska, developing techniques to aid cruisers, fallers, and buckers in recognizing and evaluating decay in Sitka spruce trees and logs. Four fungi, *Polyporus schweinitzii* Fr., *P. borealis* Fr., *Fomes pinicola*, and *P. sulphureus* (Bull.) Fr., caused 78 percent of infections in spruce. Conks were produced infrequently or not at all on living trees and in most instances frost cracks, scars, and broken tops provided the only basis for estimating presence of decay. A comparison of slow- and fast-growing trees showed no difference in volume lost through decay.

In 1950, Klein (1951) collected general information on decay and recorded many of the tree diseases found in western hemlock, Sitka spruce, and western redcedar in southeast Alaska.[4/] [5/] He also found that visible defect was related to site, diameter, and species but not to tree age or vigor. Spruce had little decay in the smaller diameter classes and relatively few cull trees.

Then in 1953, James Kimmey initiated a study of decay in standing trees as part of a general forest disease survey of Alaska. His work was a direct result of the need for decay information to strengthen the timber resource inventories in the region. Results of Kimmey's (1956) study were used for forest inventory and by 1960 were incorporated by the Forest Service into presale cruising procedures in southeast Alaska. Diameter at breast height and position of visible indicators were used to predict percentage of rot in standing hemlock, spruce, and western redcedar in southeast Alaska. Less reliable constant or flat factors based only on tree diameter were also presented.

Indicators of decay included conks, swollen knots caused by *Fomes pini*, scars, frost cracks in the main stem, rotten stubs and old dead tops protruding from the lower main stem, and rotten burls or cankers. Dead or spike tops, sucker-type limbs, dead sides, forked tops, sound mistletoe cankers, and conks more than 1 foot from the stem on limbs were abnormalities that did not consistently indicate the presence of decay. Other abnormalities not associated with decay were large mistletoe limbs, black knots, and sound burls on hemlock and large dead limbs and knotty stems on spruce.

[4/] Klein, J. A. 1951. Diseases of southeast Alaska timber trees. Unpublished first progress report, 59 p. For. Sci. Lab., Juneau, Alaska.

[5/] Klein, J. A. 1951. Defect in the climax forests of southeast Alaska. Unpublished report, 8 p., illus. For. Sci. Lab., Juneau, Alaska.

In western hemlock 10 decay-associated fungi were identified; 10 were also identified in spruce. Three of the 10 in hemlock, *Armillaria mellea* (Vahl ex Fr.) Quel., *F. pinicola*, and *F. annosus* (Fre.) Cke. caused 25.9, 22.2, and 20.5 percent, respectively, of the total cubic-foot standing tree decay. In Sitka spruce, *F. pinicola* caused 73.3 percent of the cubic-foot decay.

Foresters in British Columbia have also placed emphasis on the development of tables and equations to predict decay in standing trees as part of their forest inventory program. The effects of tree age and diameter, site, log grade, and physiographic location on presence of decay in trees have been most commonly studied (Bier and Foster 1946a, 1946b, Bier et al. 1946, Foster and Foster 1952, Browne 1956, Foster 1957).

The Study

FIELD PROCEDURES

Field data were collected on sixty seven 1/5-acre plots scattered over southeast Alaska on commerical forest land (fig. 1). Plots were chosen at random from about 680 forest inventory locations established in the mid- to late-1950's. Except for a few dangerous culls, all trees 5 inches d.b.h. and larger on each plot were felled and sectioned so that tree volumes and extent of internal decay could be determined; in all, 1,600 trees were cut. The analysis was based only on data from 532 sawtimber hemlock and 245 sawtimber spruce, all 11.0-inch d.b.h. and larger. Smaller trees, trees with forks in the main stem, and cedar were excluded.

Latitude and elevation were recorded for each plot. Tree species, diameter and age at breast height, and crown class and vigor were noted for each tree on the plots. Where applicable, number of indicators per tree, type, length, width, diameter, aspect, and position on the stem were also recorded before the trees were felled and sectioned.

Felled trees 11.0-inch d.b.h. and larger were sectioned at 16.3-foot intervals above a 1.0-foot stump, with additional cuts at breast height, midpoint of the first log, at a point where diameter inside bark equaled 40 percent of the diameter at breast height (merchantable top), and at the 6.0- and 4.0-inch tops inside bark. Additional cuts were often made to determine extent of incipient and advanced decay and to evaluate importance of external indicators. When incipient[6/] or advanced[7/] decay was found, the area affected was measured so that decay in trees could be calculated by cubic- and board-foot rules.

[6/] Incipient decay is the earliest stage of decay when the wood appears hard and firm but has a slight color change. Low grades of lumber may be manufactured from such wood, and it may be used for pulp although there may be some weakening of the fibers.

[7/] Advanced decay is a later stage when the wood is noticeably changed in structure and appearance. Strength is so reduced that the wood can usually be easily crumbled.

ANALYSIS

Gross and net tree volumes were calculated from a computer program developed to process decay data.[8] Cubic-foot volumes were computed between a 1.0-foot stump and a 4.0-inch top inside bark, while board-foot volumes (Scribner rule) were computed for 16.3-foot logs between a 1.0-foot stump and a top equal to 40 percent of the diameter at breast height, but not less than 6.0 inches inside bark.

Cubic- and board-foot defect included both incipient and advanced decay. Some sound wood was usually included. The amount depended upon the nature of the decay and scaling rules[9] applied. Sound wood defects such as broken tops, sweep, crook, shake, frost cracks, breakage, and fluting were not included in the cubic-foot deductions.

For board-foot decay, any 16-foot log that squared out over two-thirds defective was culled 100 percent. In addition to incipient and advanced decay, deductions were made for the sound-wood defects of shake and frost cracks.

Significant external indicators of decay were identified; then regression analysis was used to develop equations to predict decay percentages in standing trees. In regression analysis many variables were considered singly and combined.

Selection of important independent variables was complicated by the amount of variation in the decay data, as standard errors expressed as a percent of mean decay often exceeded 200 percent.

In the analysis, individual trees were treated as independent observations even though trees were actually sampled in groups on 1/5-acre plots.

External Indicators of Decay

Mean decay percentage in trees without external indicators was first calculated to establish a norm against which decay in trees with indicators could be compared. Mean decay percentage for trees with a specific type of indicator was then statistically compared to the sample of trees without indicators to see if the indicator was significantly related to internal decay (table 3).

Indicators found important were basal scars (fig. 2) and trunk scars (fig. 3) extending into the heartwood, frost cracks (fig. 4), broken tops in the merchantable stem (fig. 5), and conks (fig. 6). The same indicators were important in Kimmey's (1956) study. Other potential indicators such as swollen knots, caused by *Fomes pini*, rotten stubs, and rotten burls could not be evaluated as there were insufficient samples. However, these were considered significant indicators of decay in Kimmey's study, and we

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[8] Computer program ACUL, on file at Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

[9] Scaling rules are described in Forest Service Handbook 2443.71, "National Forest Log Scaling Handbook," USDA For. Serv.

Table 3--*Decay percentage in western hemlock and Sitka spruce in southeast Alaska by type of indicator*

Indicator	Trees with indicators		Decay percentage associated with a single type of indicator	
	Number[1/]	Percent	Cubic feet	Board feet[2/]
Western Hemlock:				
Basal scar	56	10.5	19.3	43.8
Trunk scar	129	24.2	13.2	31.9
Frost crack	22	4.1	7.2	17.0
Broken top[3/]	16	3.0	21.8	42.4
Conk	9	1.1	(4/)	(4/)
None	344	64.7	4.2	10.5
Total sample	532	--	--	--
Sitka Spruce:				
Basal scar	8	3.3	15.6	31.0
Trunk scar	22	9.0	13.3	29.3
Frost crack	19	7.8	22.2	36.8
Broken top[3/]	5	2.0	(4/)	(4/)
Conk	11	3.3	12.0	25.2
None	194	79.2	.4	1.3
Total sample	245	--	--	--

1/ Some trees have more than one indicator, so the total of all trees with and without indicators does not add up to total number of trees.

2/ Scribner rule.

3/ Broken top extending into merchantable sawtimber stem.

4/ Insufficient sample to calculate a meaningful average.

Figure 2.--Basal scars are open or closed injuries which penetrate the heartwood below the 1-foot stump and often extend above into the merchantable stem. Recent injuries less than 5 years old do not indicate decay.

Figure 3.--Trunk scars in the lower stem of western hemlock. Trunk scars are open or closed injuries penetrating the heartwood of the merchantable stem starting above the 1-foot stump.

Figure 4.--Frost crack in the lower stem of western hemlock with associated decay.

Figure 5.--Broken top within the merchantable stem is an indicator of decay.

Figure 6.--Fomes pini on the lower stem of western hemlock. Any conks on the main stem are indicators of decay.

Figure 7.--Black knots commonly found on western hemlock are not indicators of decay. Other imperfections that do not indicate decay are dead or broken tops above the merchantable stem, large dead branches or sucker-type limbs, forked tops, dead sides, sound burls, and conks more than 1 foot from the stem on branches.

considered them significant in our study as well. Trunk scars extending into the heartwood were the most commonly found indicators, followed by basal scars in hemlock and frost cracks in spruce. Conks were infrequently found, especially at lower elevations. A general observation was that *Fomes pini* conks are more common at higher elevations, although no supporting data exist. Trees with indicators averaged 1.8 indicators per tree for hemlock and 2.1 for spruce.

Certain injuries and imperfections in hemlock and spruce are not consistent indicators of decay. These include dead or broken tops above the merchantable stem, large dead branches or sucker-type limbs, forked tops, dead sides, sound burls, and conks more than 1 foot from the stem on branches. Black knots, commonly found on hemlock, are not indicators of decay (fig. 7).

About 65 percent of the hemlock and 79 percent of the spruce had no external indicators (table 4), and average defect for those trees was low.

Table 4--*Occurrence of sawtimber sample trees and presence of decay indicators*

Species and source of date	Trees with no indicators		Trees with indicators on:					
			Upper stem[1/]		Lower stem[2/]		Both upper and lower stem	
	No.	*Percentage*	*No.*	*Percentage*	*No.*	*Percentage*	*No.*	*Percentage*
Hemlock:								
This study	344	65	34	6	111	21	43	8
Kimmey (1956)	154	67	16	7	42	18	18	8
Spruce:								
This study	194	79	9	4	29	12	13	5
Kimmey (1956)	150	65	22	10	36	16	22	10

1/ Above the first 32-foot log.

2/ On the first 32-foot log.

The high percentage of trees with no indicators was due to sampling, as fixed plots were used in which the frequency distribution was heavily weighted to trees of smaller diameter. Decay generally increases with diameter and age, so when decay percentage is calculated on a volume basis there is more total decay than number of trees with indicators would suggest.

Distribution of sample trees by position of external indicator is also shown in table 4 contrasted with data obtained by Kimmey (1956). Distribution of trees in the two studies was similar, even though Kimmey collected his data from eight logging shows at sea level instead of at random from all commercial forest land.

Most external indicators were found on the lower stem; and when a tree had an indicator on the upper stem, it usually had an indicator on the lower stem as well. The important point is that most trees in both studies had no external indicators, and variation in decay among those that did was considerable.

Other Variables Related to Decay

Tree age.--Decay percentages were significantly related to tree age (fig. 8). Hemlock and spruce less than about 100 years of age are generally sound, but older hemlock deteriorates at a faster rate than spruce. At 300 to 400 years of age, spruce is relatively free of rot; whereas decay in hemlock averages 30 to 40 percent on a board-foot basis. Meaningful data were lacking beyond about 400 years of age. Decay percentages based on the board-foot scale were roughly twice those based on the cubic-foot scale.

The approximate relationships between decay percentages and tree age, shown in figure 8, are for data grouped by 50-year age class. Correlations were very weak, accounting for less than 12 percent of the variation for both cubic- and board-foot decay percentages of both species. Curves were fit by eye to hemlock data, as more precise fits would require solutions to nonlinear equations. This was not justified as it is not practical to use age as a predictor of defect in rotten trees.

Figure 8 gives the impression that decay in spruce is more variable than in hemlock but this is not the case. Trends were less well defined for spruce because there were fewer observations. No attempt was made to fit a curve to the spruce data.

Tree diameter.--Amount of decay was significantly related to tree diameter, but the relationships were weak. For hemlock, 9 percent of the variation in percent cubic-foot decay and 6 percent in percent board-foot decay was accounted for, and for spruce, 4 and 4 percent, respectively. Although correlations were weak, trends were clear when data were grouped by 4-inch diameter class (table 5).

Probability of occurrence of decay increases greatly with tree diameter, especially for hemlock. More than 50 percent of the hemlock over 23 inches had external indicators, and decay averaged 44 percent on a board-foot basis. Spruce was much less defective.

Kimmey (1956) used tree diameter and position of external indicators to predict decay percentages in standing trees. He first sorted his data by position of external indicator into the following classes:

--No external indicator
--External indicators either on or above the first 32-foot log
--External indicators both on and above the first 32-foot log

He showed graphically that decay percentages were related to tree diameter within indicator class, and then he prepared tables for each species showing cubic- and board-foot decay percentages by indicator class and tree diameter.

Kimmey's basic data were reanalyzed using computer programs not available to him at the time, and our conclusions are that:

1. Hemlock trees with indicators on either the upper or lower stem were correctly pooled into one class; and decay percentage was significantly related to tree diameter for trees with indicators either on or above the

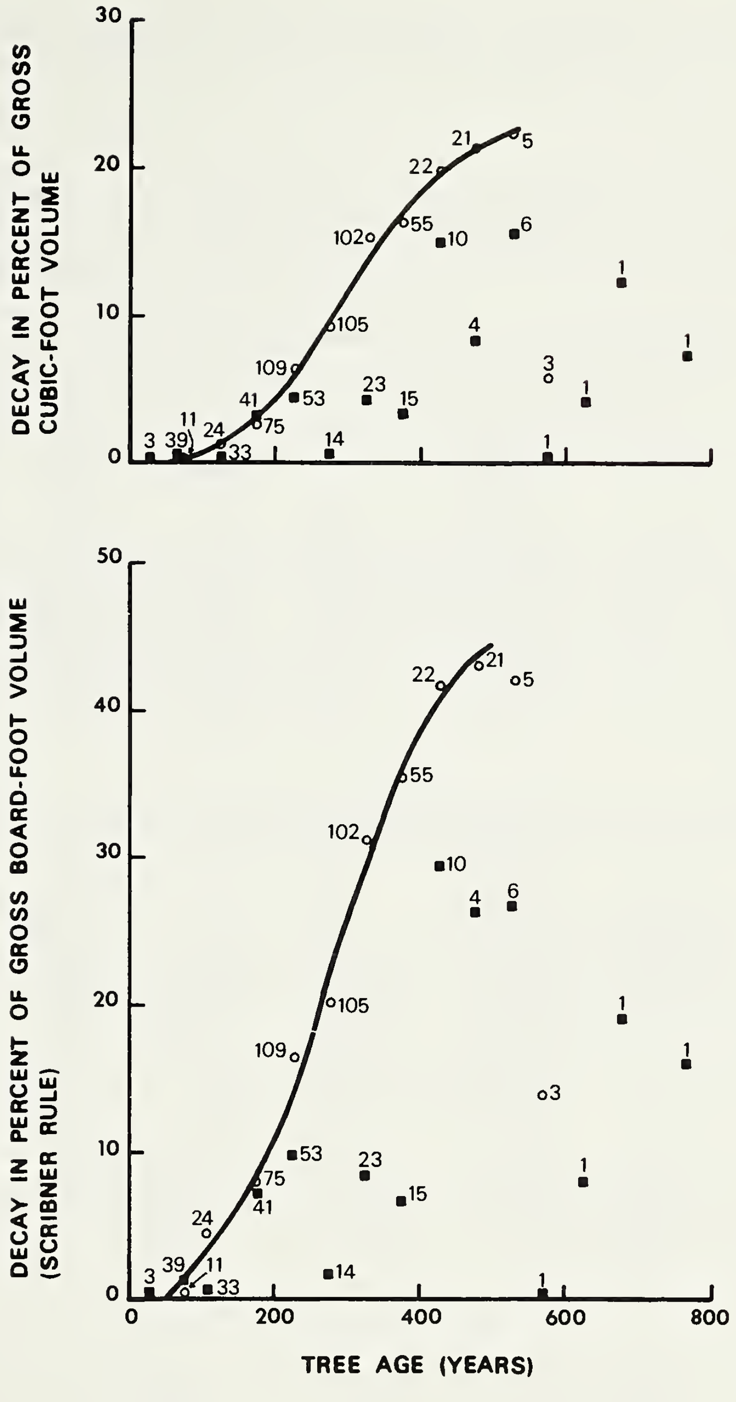

Figure 8.--Relationships between cubic- and board-foot decay percentages and tree age for all sample trees. Basic data were averaged by 50-year age class. Solid free hand curves and circles (o) are for western hemlock, squares (■) for Sitka spruce.

Table 5--*Decay percentage in western hemlock and Sitka spruce in southeast Alaska by 4-inch diameter classes*

D.b.h. (Inches)	Trees	Trees with indicators	In trees with no indicators		In trees with indicators	
			Cubic feet	Board feet 1/	Cubic feet	Board feet 1/
	Number	*- - - - - - - - - Percentage - - - - - - - - - -*				
Western Hemlock:						
11-13	126	17.5	1.7	5.7	15.0	41.9
14-17	137	21.9	3.3	8.5	18.0	44.6
18-21	117	43.6	7.5	17.7	18.4	40.3
22-25	71	54.9	5.9	12.8	22.4	35.2
26-29	47	48.9	8.5	17.4	23.3	44.0
30-33	19	68.4	5.4	13.5	32.9	57.3
34-37	7	57.1	0.0	1.3	28.0	45.5
38-41	6	66.7	11.0	24.0	26.9	50.8
42-45	2	100.0	--	--	25.2	50.0
All trees	532	35.4	4.2	10.5	20.9	43.9
Sitka Spruce:						
11-13	35	14.3	0.2	1.0	1.1	4.9
14-17	32	18.8	.1	.2	3.1	5.9
18-21	58	13.8	.1	.2	23.9	47.9
22-25	33	18.2	.5	1.2	9.8	27.2
26-29	24	25.0	.1	.2	14.2	30.3
30-33	19	15.8	1.7	3.8	10.6	19.0
34-37	8	37.5	1.0	2.2	9.6	22.3
38-41	18	33.3	.3	.8	9.9	21.0
42-45	8	37.5	1.3	1.4	23.0	43.3
46-49	4	25.0	4.4	24.3	.4	6.0
50+	6	66.7	1.2	2.5	25.5	43.8
All trees	245	21.0	.4	1.3	14.6	30.7

1/ Scribner rule.

first 32-foot log, although the correlations were very weak. The relationship was nonsignificant for trees with indicators both on and above the first 32-foot log and a constant or flat factor should have been used. There were only 20 trees in the class; with the large amount of variation it was not possible to show a significant correlation between decay percentage and tree diameter.

2. The only significant correlation found for spruce was for trees without indicators. All other cubic- and board-foot correlations between decay percentage and tree diameter were nonsignificant and constant or flat decay factors should have been used.

When hemlock and spruce data from the current study were analyzed in the same way, only trees without indicators showed significant but weak correlations between percent decay and tree diameter. All others were nonsignificant, indicating that constant or flat factors should be used or some form of improved model developed using other combinations of variables.

Latitude and elevation.--Hemlock is generally most defective in the northern areas of southeast Alaska (table 6). This holds for trees with or without external indicators. Lower mean decay at Yakutat, an area of youthful, glacial outwash soils, was attributed to tree age. Hemlock at Yakutat were much younger and sounder than hemlock felled in other geographical areas of southeast Alaska.

Table 6--*Mean decay in western hemlock and Sitka spruce in southeast Alaska by geographic area*

Geographic area	Mean latitude of sample plots in degrees	Number of trees	Mean percentage decay in all sample trees ±standard error	
			cubic-feet	board feet[1/]
Western Hemlock:				
Yakutat	59.4	41	5.6 ± 2.11	12.3 ± 3.23
Juneau	57.9	149	17.2 ± 1.66	37.4 ± 3.21
Sitka	57.8	97	10.7 ± 1.98	21.6 ± 3.45
Petersburg	56.6	175	8.0 ± 1.01	18.3 ± 2.15
Ketchikan	55.5	111	3.5 ± .82	9.0 ± 1.79
Sitka Spruce:				
Yakutat	59.4	152	2.9 ± .74	6.7 ± 1.46
Juneau	57.9	34	5.9 ± 2.30	11.9 ± 4.16
Sitka	57.8	33	1.7 ± 1.47	3.2 ± 2.50
Petersburg	56.6	19	6.2 ± 2.50	14.3 ± 5.03
Ketchikan	55.5	7	1.2 ± .91	1.7 ± 1.13

[1/] Scribner rule.

The great difference in average decay for trees in the Juneau and Sitka areas, both at similar latitude, is probably due to differences in climate. Most plots in the Juneau area were located along the narrow mainland strip where growing season temperatures are cooler than in the islands further west. In hemlock, latitude accounted for 8 percent of the variation in percentage of both cubic-foot and board-foot decay.

Most commercial forest land in southeast Alaska is located below 500 feet, so a meaningful analysis of the effect of elevation was not possible. Only three of the study plots were located above 500 feet. For the hemlock data, percentage of cubic-foot decay was negatively correlated with elevation indicating lower decay at higher elevations than at sea level; but only 5 percent of the variation was accounted for. For spruce the correlation between decay percentage and elevation was nonsignificant.

Development of Prediction Equations

Simple regression.--In addition to variables already mentioned, others were analyzed both singly and in combination, including slope and aspect of the field plots, crown position, crown condition, and radial growth of each tree, presence or absence of external and specific indicators, and total number of indicators. Singly, most variables were highly significantly correlated with decay percentages; but relationships were weak, accounting for only 2 to 40 percent of the variation (table 7). Considerable unexplained variation remained. In fitting equations, all measurements were treated as separate observations.

Means, standard deviations (S), and standard errors (SE) of the raw data before regression analysis were as follows:

	Number of trees	Percentage of cubic-foot decay			Percentage of board-foot decay (Scribner rule)		
		Mean	±S	±SE	Mean	±S	±SE
Hemlock	532	10.1	16.82	0.73	22.3	32.91	1.43
Spruce	245	3.4	9.80	.63	7.4	18.83	1.20

The coefficient of variation (S ÷ mean), for example, for average percentage of cubic-foot decay in hemlock was 166.5 percent. It was apparent that high standard deviation and low correlations would make predictions of decay in individual trees imprecise. This poor showing, however, is probably typical of data collected in cull studies, though seldom reported.

Considered singly, the variables accounted for up to 28 percent of the variation in percentage of hemlock board-foot decay and up to 40 percent for spruce (table 7). Standard deviations about regression remained high, especially for percentage of board-foot decay. The most important variables were position and number of external indicators.

Table 7--*Coefficients of determination and standard deviations of simple linear regression for estimating decay in percent of gross cubic- and board-foot (Scribner rule) volume in western hemlock and Sitka spruce in southeast Alaska*

Independent variable	Western hemlock				Sitka spruce			
	Percentage cubic-foot decay		Percentage board-foot decay		Percentage cubic-foot decay		Percentage board-foot decay	
	Coefficient of determination1/	Standard deviation from regression	Coefficient of determination1/	Standard deviation from regression	Coefficient of determination1/	Standard deviation from regression	Coefficient of determination1/	Standard deviation from regression
1. D.b.h.	0.09**	16.1	0.06**	32.0	0.04**	9.6	0.04**	18.5
2. Age	.11**	15.9	.11**	31.1	.08**	9.4	.08**	18.1
3. Elevation	.05**	16.4	.03**	32.5	.01	9.8	.01	18.8
4. Aspect	.00	16.8	.00	32.9	.02*	9.7	.02*	18.6
5. Slope	.003	16.8	.002	32.9	.02*	9.7	.02*	18.6
6. Latitude	.09**	16.1	.08**	31.5	--	--	--	--
7. Crown position	.01**	16.7	.02**	32.7	.00	9.8	.00	18.9
8. Crown condition	.07**	16.2	.07**	31.7	.04**	9.6	.04**	18.4
9. Best 10-year radial growth	.07**	16.2	.07**	31.8	.04**	9.6	.05**	18.4
10. Indicator codes 0, 1, 2, 3	.28**	14.3	.28**	28.0	.34**	8.0	.40**	14.6
11. Presence or absence of indicators	.22**	14.8	.24**	28.8	.34**	8.0	.40**	14.6
12. Number of indicators	.25**	14.6	.25**	28.5	.35**	7.9	.39**	14.8
13. Geographic area	.09**	16.1	.09**	31.4	.00	10.9	.00	20.1

1/ Indicates the proportion of the variation in decay percentage that is associated with the regression.

** Significant at the 1-percent level of probability.
* Significant at the 5-percent level of probability.

Multiple regression.--Several combinations of independent variables were tested in multiple regression, but even the best models did a poor job of predicting decay. Maximum variation accounted for in board-foot decay percentage was 34 percent for hemlock and 46 percent for spruce. Much residual variation remained, and most models were biased.

Diameter at breast height was significant when considered alone but in multiple regression was nonsignificant or of little value. Use of a presence or absence code essentially separated the data into two groups, trees with external indicators and trees without. Some additional precision was gained by knowing total number of indicators on a tree (table 8).

Table 8--*Simple and multiple linear regression for estimating decay in percent of gross cubic- and board-foot (Scribner rule) volume in western hemlock and Sitka spruce in southeast Alaska*

Regression equation Y = estimated decay in percent of gross cubic-foot volume	Coefficient of determination1/	Standard deviation from regression	Regression equation Y = estimated decay in percent of gross board-foot volume	Coefficient of determination1/	Standard deviation from regression
Western Hemlock:					
Y = 4.93 + 0.7845 (d.b.h.)	0.09**	16.1	Y = -1.46 + 1.2412 (d.b.h.)	0.06**	32.6
Y = 4.25 + 16.60 (POA)2/	.22**	14.8	Y = 10.54 + 33.40 (POA)2/	.24**	28.8
Y = 5.28 + 7.77 (Number of indicators)	.25**	14.6	Y = 12.86 + 15.24 (Number of indicators)	.25**	28.5
Y = -262.67 + 4.69 (Latitude) + 12.65 (Trunk scars) + 11.41 (Basal scars) + 20.57 (Broken top) + 12.85 (Frost cracks) + 20.57 (Conks)	.37**	13.4	Y = -489.75 + 8.80 (Latitude) + 26.43 (Trunk scars) + 21.14 (Basal scars) + 29.22 (Broken top) + 24.05 (Frost cracks) + 34.90 (Conks)	.34**	26.9
Sitka Spruce:					
Y = -1.19 + 0.1865 (d.b.h.)	.04**	9.6	Y = -1.49 + 0.362 (d.b.h.)	.04**	18.5
Y = 0.44 + 14.13 (POA)2/	.34**	8.0	Y = 1.26 + 29.41 (POA)2/	.40**	14.6
Y = 1.29 + 4.89 (Number of indicators)	.35**	7.9	Y = 3.16 + 0.984 (Number of indicators)	.39**	14.8
Y = 0.51 + 10.45 (Trunk scars) + 8.01 (Basal scars) + 13.92 (Frost cracks) + 18.06 (Conks)	.42**	7.5	Y = 1.55 + 20.66 (Trunk scars) + 19.37 (Basal scars) + 29.16 (Frost cracks) + 33.18 (Conks)	.46**	13.9

1/ Indicates the proportion of the variation in Y that is associated with the regression.

2/ Presence or absence of external indicators. POA = 1 if indicators are present; 0 otherwise.

** Significant at the 1-percent level of probability.

Prediction equations were also developed which included specific indicators of decay such as presence or absence of trunk scars, basal scars, etc. (table 8). These equations accounted for more variation than did other combinations of variables; but field application would tend to introduce biases as important individual indicators might easily be missed, resulting in an underestimate of decay.

The hemlock decay data showed a definite south to north gradient (tables 6 and 8). This suggested that decay prediction equations for hemlock would be biased unless the gradient effect was taken into account. Also the gradient did not seem to be strictly related to latitude, but to differences in climate as explained earlier.

Decay percentages were also related to location of external indicators, and most differences between classes were significant (table 9).

Table 9--*Means and standard errors of decay percentages in western hemlock and Sitka spruce in southeast Alaska by position of external indicator*

Position of external indicator	Sample size	Cubic-foot decay		Board-foot decay (Scribner rule)	
		Mean decay percentage	Standard error of the mean	Mean decay percentage	Standard error of the mean
Western Hemlock:[1/]					
0 None	344	4.2	0.55	10.5	1.29
1 Above the first 32-foot log	34	13.6 [2/]	2.79	30.6	5.87
2 On the first 32-foot log	111	18.1	1.77	39.7	3.23
3 Both on and above the first 32-foot log	43	34.0	3.64	65.6	5.17
Sitka Spruce:[3/]					
0 None	194	.4	.12	1.3	.37
1 Above the first 32-foot log	9	7.8	4.70	15.6	8.39
2 On the first 32-foot log	29	16.4	3.31	35.1	5.63
3 Both on and above the first 32-foot log	13	15.1	5.00	31.2	9.12
Classes 2 and 3 combined[4/]	42	16.0	2.73	33.9	4.75

[1/] Separation of data into classes by position of external indicator accounted for 30 percent of the variation in cubic-foot decay percentage and 29 percent of the variation in board-foot decay percentage.

[2/] Any two means not joined by the same line are significantly different. Any two means joined by the same line are not significantly different at the 95-percent level of probability.

[3/] Separation of data into classes by position of external indicator accounted for 37 percent of the variation in cubic-foot decay percentage and 43 percent of the variation in board-foot decay percentage.

[4/] For spruce, means in classes 2 and 3 are not significantly different. The two classes should be combined since trees with indicators on both the upper and lower stems should on the average have more decay than trees with indicators only on lower stem. This, then, defines three classes of trees--those with no indicators, those with indicators above the first 32-foot log, and those with indicators on the first 32-foot log or with indicators both on and above the first 32-foot log.

Multiple regression with dummy variables.--After several models were tested, it was concluded that a straight-forward solution would be to develop an equation based upon smoothed class means. This was possible as the two most important independent variables--position of the external indicators and geographical area--were both qualitative variables, each at four levels as follows:

Position of external indicator	Geographical area
0 None	1 Ketchikan
1 Above the first 32-foot log	2 Petersburg
2 On the first 32-foot log	3 Sitka
3 Both on and above the first 32-foot log	4 Juneau

Relationships between decay percentages and the two independent variables were developed by solving the general equation:

$$Y = b_0 + b_1x_1 + b_2x_2 \; . \; . \; . + b_6x_6$$

where: Y = percent of gross volume that is decay;

x_1 = 1 for indicators above the first 32-foot log, 0 otherwise;

x_2 = 1 for indicators on the first 32-foot log, 0 otherwise;

x_3 = 1 for indicators both on and above the first 32-foot log, 0 otherwise;

x_4 = 1 for trees in the Petersburg Unit, 0 otherwise;

x_5 = 1 for trees in the Sitka Unit, 0 otherwise;

x_6 = 1 for trees in the Juneau Unit, 0 otherwise;

b_i = regression constants.

The constant term b_0 was an estimate of Y for trees without indicators in the Ketchikan Unit. Additional variables like tree diameter and interactions between diameter and indicator code were also tested and discarded as they were not important.

This equation worked reasonably well with hemlock but not for spruce, probably because there were too few spruce samples in most classes and variability of the data was too great. Spruce is sounder than hemlock, and trees with several indicators often had little defect.

Mean decay percentages for hemlock before regression had few observations in many cells (table 10). Regression solutions for hemlock, shown below, and given in tabular form in table 1, effectively smoothed the cell values.

Hemlock percent cubic-foot decay

$$Y = 8.44x_1 + 12.45x_2 + 29.13x_3 + 1.95x_4 + 6.71x_5 + 10.24x_6$$
$$R^2 = 0.35$$ [10/]

10/ R^2 is the proportion of total variation about the mean ($\bar{Y}$) that is explained by the regression.

Table 10--*Mean decay percentages in western hemlock in southeast Alaska by position of external indicator and geographic area*

Position of external indicator	Ketchikan		Petersburg		Sitka		Juneau	
	Number	*Percentage*	*Number*	*Percentage*	*Number*	*Percentage*	*Number*	*Percentage*
Cubic-foot decay:								
0 None	81	1.2	112	3.2	70	4.4	81	8.7
1 Above the first 32-foot log	7	5.0	11	8.7	5	15.4	11	22.5
2 On the first 32-foot log	17	10.3	33	14.2	18	20.3	43	23.2
3 Both on and above the first 32-foot log	6	14.4	19	25.2	4	70.7	14	43.8
Board-foot decay:[1/]								
0 None	81	3.0	112	7.7	70	10.7	81	21.8
1 Above the first 32-foot log	7	8.9	11	23.5	5	27.2	11	53.0
2 On the first 32-foot log	17	30.1	33	31.0	18	45.6	43	47.6
3 Both on and above the first 32-foot log	6	30.5	19	55.6	4	99.0	14	84.6

[1/] Scribner rule.

Hemlock percent board-foot decay

$$Y = 0.91 + 18.79x_1 + 26.37x_2 + 53.78x_3 + 5.41x_4 + 12.66x_5 + 22.47x_6$$

$$R^2 = 0.35$$

For spruce the best solution was simply to use the mean decay percentages by position of external indicator (table 2).

Decay percentages were significantly related to tree diameter for spruce and hemlock trees without indicators. However, the relationships were weak, accounting for less than 10 percent of the variation. Also solutions of the equation gave negative values for small diameter trees in the 12- to 14-inch class. Therefore these equations will not be presented.

Application of Results

Estimation of decay in standing hemlock and spruce lacks the precision that most timber cruisers would like. Although decay factors have been applied to standing trees in southeast Alaska for almost 20 years, there is no guarantee they will give unbiased estimates when applied to localized timber sales (see footnote 2). They are mostly appropriate for large inventories where it is not possible to do destructive sampling and where decay percentages tend to average out.

Reanalysis of Kimmey's (1956) basic data along with data collected here suggests that complex decay prediction equations are unnecessary.

Most equations account for little of the total variation and are biased. Although crude, it is much safer to use general class means. Then users are not misled into thinking the decay factors are better than they really are.

If timber cruisers are willing to risk the accuracy of their cruises by continuing to use standing-tree decay factors, then values given for hemlock in table 1 and for spruce in table 2 are recommended. These are simpler to apply than previously used Kimmey factors (1956), as tree diameter need not be known.

The most easily applied regression relationships for spruce are between decay percentage and location of external indicators. Position of external indicators and geographic area are needed to estimate decay percentages in hemlock. The four recognized geographic areas are Ketchikan, Petersburg, Sitka, and Juneau (fig. 1). Too few hemlock were sampled at Yakutat, and most were sound, so it is recommended that the mean values from table 9 be used for hemlock at Yakutat.

Users of the tables are also cautioned that for safety reasons obvious cull trees were not sampled in this study. Therefore, the values in tables 1 and 2 should not be applied to obvious culls in the field. Instead the trees should be given an indicator code 4, meaning complete cull.

There are at least two alternatives to using decay factors for estimating decay in standing trees. One is to rely on information from felled trees collected from nearby logging operations. Such information could be used to develop local decay factors. Another is to use fall, buck, and scale cruising (Johnson and Hartman 1972). Fall, buck, and scale cruising is being used on some sales in Alaska. Interest in its use is growing, as there is no suitable alternative but to section defective timber if reliable net volumes and values are to be estimated.

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Farr, Wilbur A., Vernon J. LaBau, and Thomas H. Laurent
1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-204, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees on sixty seven 1/5th-acre plots were dissected so that a method could be developed for making unbiased estimates of decay in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on commercial forest land in southeast Alaska. Decay in both species was related to many variables, but relationships were weak. For hemlock, decay was best related to position of external indicators and to geographic location; decay in hemlock increased to the north. For spruce, the most useful predictor of decay was position of external indicators. These derived decay factors are useful for large-scale inventories; their reliability cannot be guaranteed on local timber sales.

KEYWORDS: Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, decay (-log quality.

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1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-204, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees on sixty seven 1/5th-acre plots were dissected so that a method could be developed for making unbiased estimates of decay in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on commercial forest land in southeast Alaska. Decay in both species was related to many variables, but relationships were weak. For hemlock, decay was best related to position of external indicators and to geographic location; decay in hemlock increased to the north. For spruce, the most useful predictor of decay was position of external indicators. These derived decay factors are useful for large-scale inventories; their reliability cannot be guaranteed on local timber sales.

KEYWORDS: Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, decay (-log quality.

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